

# Towards Decision Support Technology Platform for Modular Systems

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The survey methodological paper addresses a glance to a general decision support platform technology for modular systems (modular/composite alternatives/solutions) in various applied domains. The decision support platform consists of seven basic combinatorial engineering frameworks (system synthesis, system modeling, evaluation, detection of bottleneck, improvement/extension, multistage design, combinatorial evolution and forecasting). The decision support platform is based on decision support procedures (e.g., multicriteria selection/sorting, clustering), combinatorial optimization problems (e.g., knapsack, multiple choice problem, clique, assignment/allocation, covering, spanning trees), and their combinations. The following is described: (1) general scheme of the decision support platform technology; (2) brief descriptions of modular (composite) systems (or composite alternatives); (3) trends in moving from choice/selection of alternatives to processing of composite alternatives which correspond to hierarchical modular products/systems; (4) scheme of resource requirements (i.e., human, information-computer); and (5) basic combinatorial engineering frameworks and their applications in various domains.

*Keywords:* decision support, platform technology, modular systems, system design, combinatorial optimization, systems engineering, engineering frameworks, decision support system

## 1. Introduction

In recent years the significance of modular products/systems and corresponding product families (or product lines) has been increased (e.g., [15,16,17,40,92,93,94]). Some basic research directions in the fields of modularity and modular systems are briefly pointed out in Table 1 (e.g., mechanical systems, manufacturing systems, robots, software systems, computing systems, electronic systems, Web-based systems, communication protocols, control systems).

**Table 1.** Basic research directions in modularity/modular systems

Research direction	Some sources
1. Modularity	[1,2,3,8,19,30,39,78]
2. Modular products/systems	[4,15,32,39,40,41,46,48,67,83]
3. Modularity and commonality research	[9,21,23,26,28,31,48]
4. Products/systems configuration	[13,14,25,38,46,48,50,53,55,67,79,80,90,95,96,97,98,99,100,102]
5. Reconfiguration, reconfigurable systems	[5,6,7,11,12,18,22,45,46,48,50,53,60,67]
6. Adaptable design of products/systems	[18,24,35,37,42,76,101]
7. Design of products/systems for variety	[20,26,27,77,78,86]
8. Product families	[14,16,21,22,28,34,40,48,93,94]
9. Product platforms	[14,17,33,34,40,43,44,78,81,88,92,93,94]
10. Approaches to general decision support platform	[14,25,59,67,90,100,102]

Fig. 1 depicts a traditional scheme of product platform efforts for a certain product domain (e.g., buildings, software, manufacturing systems, aerospace systems, ships, mechatronic systems, computing systems, etc.) [88,92,93,94].

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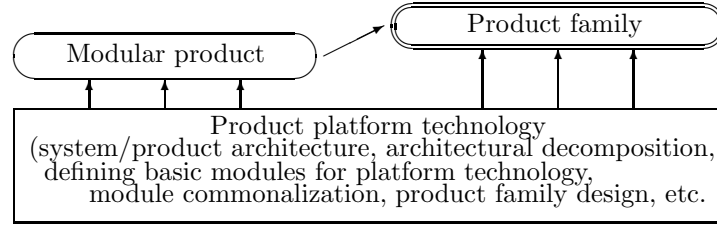


Fig. 1. Traditional scheme of product platform technology

Here, a general decision support platform technology is briefly described that can be used for many engineering/management domains (Fig. 2) [48,59,67].

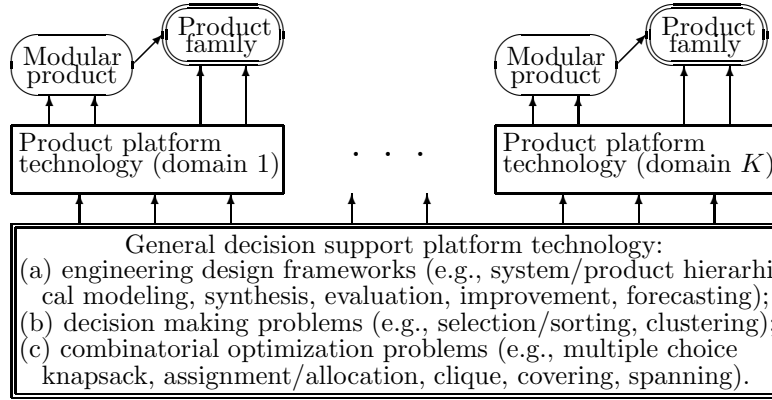


Fig. 2. General decision support platform for modular systems

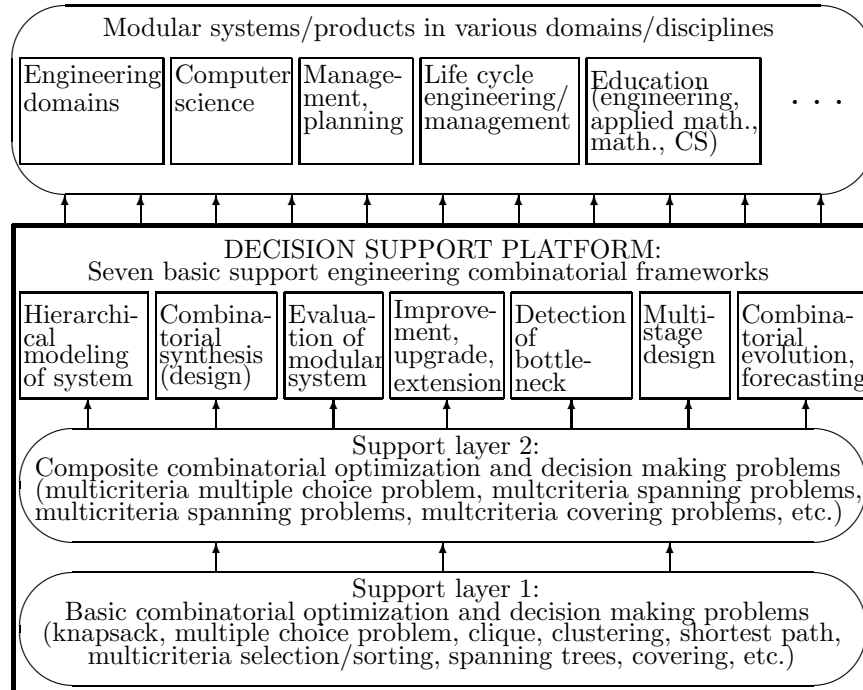


Fig. 3. Scheme of general decision support platform technology

## 2. Scheme of General Decision Support Platform

A scheme of the proposed general decision support platform technology is shown in Fig. 3. Here, two support layers of decision making and combinatorial optimization problems/models are used: (i) basic

problems, (ii) composite problems.

### 3. Towards Hierarchical Modeling of Modular Systems

In general, knowledge representation in product design systems is systematically studied in [10,36]. Here, modular systems (or corresponding (modular/composite alternatives/solutions)) are examined as the following (i.e., system configuration) (e.g., [48,50,57,59,67]):

- (a) a set of system elements (components, modules),
- (b) a set of system elements and their interconnections (i.e., a special structure over the system elements, e.g., hierarchy, tree-like structure).

Fig. 4 depicts a composite (modular) system, consisting of  $n$  components/modules (and corresponding three design alternatives DAs for each component/module).

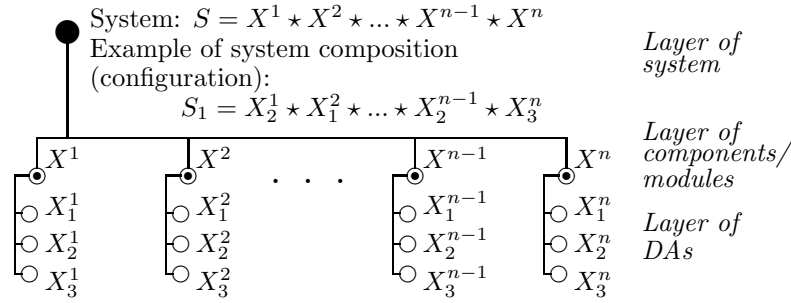


Fig. 4. Illustration for composite (modular) system

The system composition problem can be based on multiple choice problem or morphological clique problem (while taking into account compatibility between the selected DAs) [46,48,50,53,55,67]. Fig. 5 illustrates the system composition for a four-component system while taking into account compatibility of DAs (concentric presentation).

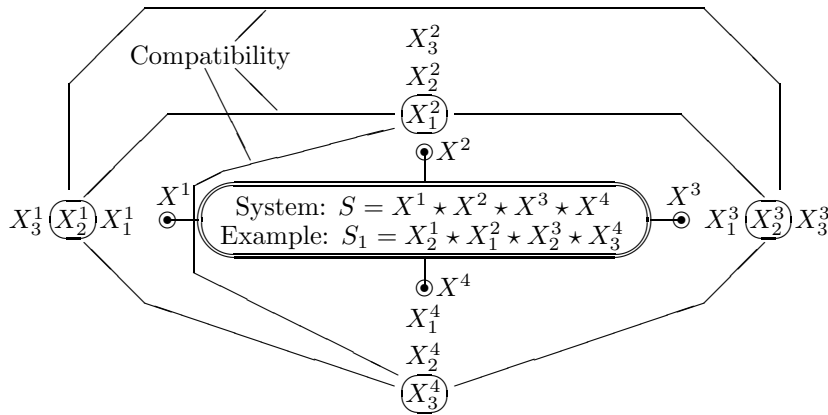


Fig. 5. Concentric presentation of system composition

In the case of DAs, the following information is considered (i.e., morphological system structure) (e.g., [46,48,50,57,67]): (a) estimates of DAs (e.g., vector estimates, ordinal estimates, interval multiset estimates), (b) estimates of compatibility between DAs of different system components (e.g., ordinal estimates, interval multiset estimates).

Further, two illustrations are presented: (i) hierarchical (tree-like) system model (Fig. 6) and (ii) hierarchical system model with common modules for subsystems (Fig. 7).

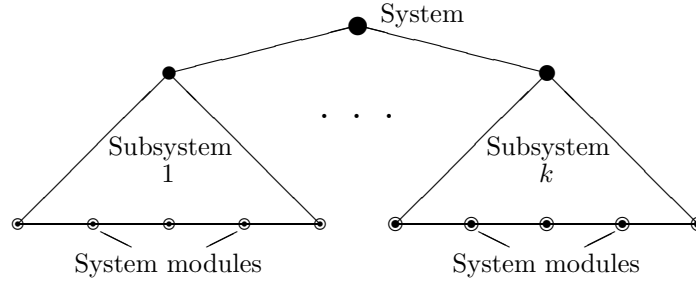


Fig. 6. Hierarchical (tree-like) system model

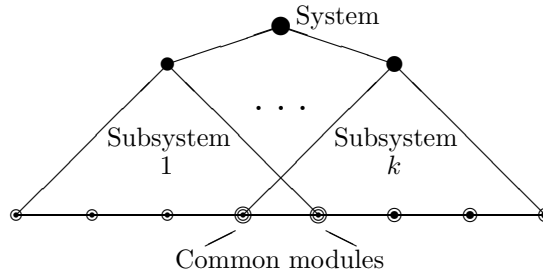


Fig. 7. Common modules for subsystem

#### 4. Decision Problem Trends from Alternative To Composite Alternative

Main decision problem trends in moving process from alternative(s) to composite alternative(s) (i.e., composite systems) is depicted in Fig. 8 [46,48,49,59,67].

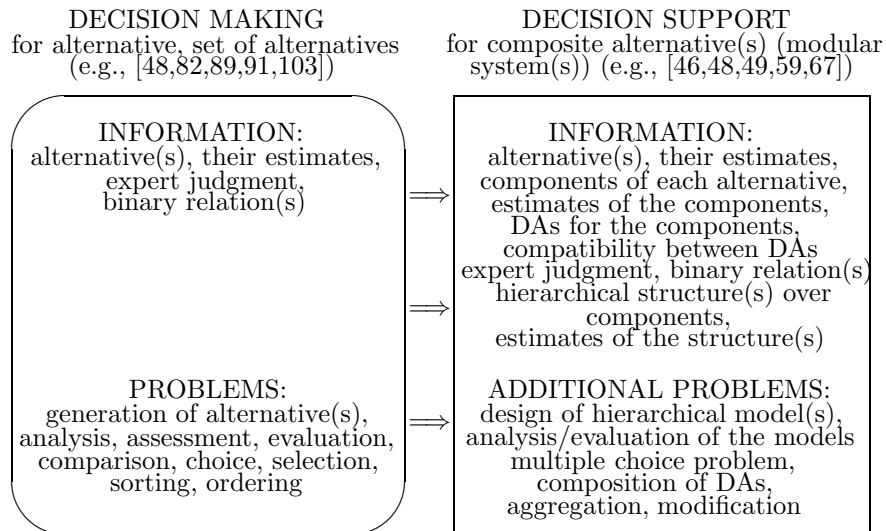


Fig. 8. Moving from alternative(s) to composite (modular) alternative(s)

Evidently, the decision problems became to be more complicated by several directions, for example:

(a) hierarchical structures (models) of composite alternatives and their processing (design of hierarchical structure/model, evaluation, comparison, modification, aggregation);

(b) components of each composite alternative and DAs for each component (including assessment and evaluation of the DAs), assessment and evaluation of compatibility between DAs for alternative components.

In addition, it is reasonable to point out basic types of resources and corresponding kinds of resource requirements (i.e., human resources, information-computing requirements (Fig. 9).

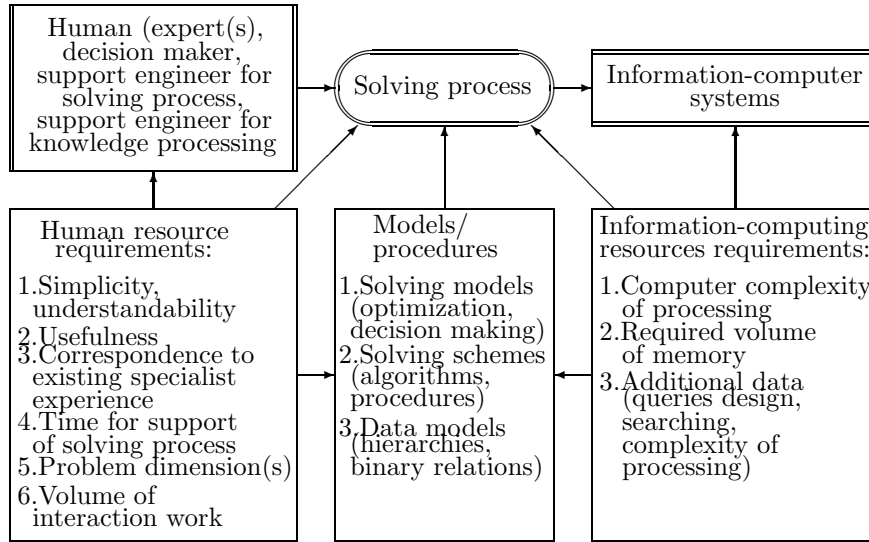


Fig. 9. Scheme of resource requirements

## 5. Support Problems/Frameworks and Applications

Seven support combinatorial engineering framework for modular systems (composite alternatives) have been suggested by the author (e.g., [48,49,59]):

1. Morphological system design (combinatorial synthesis) based on hierarchical multicriteria morphological design (HMMD) approach (an hierarchical extension of morphological analysis while taking into account ordinal estimates of DAs and their compatibility) [46,48,53,55,67].
2. Design of hierarchical system models (i.e., tree-like structures) [57,67]:
3. Evaluation of hierarchical modular system [48,61,67].
4. Detection of system bottlenecks [58,62,67].
5. System improvement/extension [46,48,60,67].
6. Multistage system design (design of system trajectory) [63,67].
7. Combinatorial system evolution and forecasting [64,67,73,74].

Table 2 contains some applied examples for the combinatorial engineering frameworks above.

In the case of grouping the application examples by large discipline domains (Fig. 3), the following groups for application examples are obtained:

1. Engineering domains: control engineering (management system for smart homes) [66,67], communication engineering (GSM system, standard for multimedia information processing) [65,67,73], protocol engineering (communication protocol ZigBee) [56,65,67,74], sensor/telemetry systems [67,72,75], civil engineering (building from the viewpoint of earthquake engineering) [48,71].
2. Computer science: software engineering [48], information systems [46], configuration of applied Web-based information systems [51,67], composite retrieval [46,54,67].
3. Management, planning: geological planning [46], investment [46], medical treatment [48,67,69].
4. Life cycle engineering/management: concrete technology (design, manufacturing, transportation, utilization) [48,68].
5. Education (engineering, applied mathematics, CS): design and combinatorial modeling of courses on system design [46,48,67].

**Table 2.** Examples of applications (combinatorial engineering frameworks)

Support engineering framework	Some application(s)
1. Combinatorial synthesis	Modular software [47,48] Management system in smart home [66,67] GSM communication network [53,67] Wireless sensor element [67,75] On-board telemetry system [67,72] Medical treatment [48,67,69] Vibration conveyor [46] Concrete technology [48,68] Immunoassay technology [48,70] Web-based information system [51,67] Communication protocol ZigBee [56,65,67] Standard for multimedia [65,67,73] Composite product in electronic shopping [54,67]
2. Hierarchical system modeling	Management system in smart home [66,67] Communication protocol ZigBee [56,65,67,74] Concrete technology [48,68] Immunoassay technology [48,70] Standard for multimedia [65,67,73] On-board telemetry system [67,72] Medical treatment [48,67,69] Vibration conveyor [46] Wireless sensor element [67,75] Web-based information system [51,67] Composite product in electronic shopping [54,67] Building [48,71]
3. Evaluation of system	Composite product in electronic shopping [54,67] Wireless sensor element [67,75] Vibration conveyor [46] Concrete technology [48,68] Immunoassay technology [48,70] On-board telemetry system [67,72] Management system in smart home [66,67] Communication protocol ZigBee [56,65,67,74] Standard for multimedia [65,67] Medical treatment [48,67,69] Web-based information system [51,67] Building [48,71]
4. Detection of bottlenecks	Web-based information system [51,67] On-board telemetry system [67,72] Wireless sensor element [67,75]
5. System improvement/extension	Management system in smart home [66,67] On-board telemetry system [67,72] Wireless sensor element [67,75] Building [48,71]
6. Multistage design	Modular education courses [64,67] Web-based information system [51,67]
7. Evolution and forecasting	Modular education courses [64,67] Standard for multimedia [67,73] Communication protocol ZigBee [67,74] Web-based information system [51,67]

## 6. Conclusion

This paper contains the author's glance to a general decision support platform technology for modular systems (i.e., composite/modular alternatives). Evidently, the decision support platform is an open system and can be extended, for example: (i) additional combinatorial optimization models (e.g., [29,84,85,87]), (ii) additional composite combinatorial frameworks (e.g., [52,67]). It is reasonable to point out the several future research directions for the described decision support platform:

1. the platform may be considered as a prospective tool for modular system design, evaluation, and maintenance;
3. the platform may be interesting from the viewpoint of new decision support systems for composite (modular) alternatives; and
2. the platform is a significant direction for contemporary support systems in the field of system/product life cycle engineering/management.

## REFERENCES

1. P.J. Agerfalk, S. Brinkkemper, C. Gonzalez, B. Henderson-Seller, F. Karlsson, S. Kelly, J. Ralyte, Modularization constructs in method engineering: towards common ground? *IFIP Int. Federation for Information Processing* 244 (2007) 359–368.
2. K.K. Ali, M.S. Saed, *Product Design for Modularity*. Kluwer, Norwell, 2002.
3. C.Y. Baldwin, K.B. Clark, *Design Rules: the Power of Modularity*. MIT Press, Cambridge, Mass., 2000.
4. O. Berman, N. Ashrafi, Optimization models for reliability of modular software systems. *IEEE Trans. on Soft. Eng.* 19(11) (1993) 1119–1123.
5. Z. Bi, S. Lang, W. Shen, L. Wang, Reconfigurable manufacturing systems: the state of the art. *Int. J. of Production Research* 46(4) (2008) 967–992.
6. Ch. Bobda, *Introduction to Reconfigurable Computing*. Springer, 2007.
7. K. Bondalapati, V.K. Prasanna, Reconfigurable computing systems. *Proc. of the IEEE* 90(7) (2002) 1207–1217.
8. Y. Cai, K.J. Sullivan, A value-oriented theory of modularity in design. *ACM SIGSOFT Software Engineering Notes* 30(4) (2005) 1–4.
9. Y. Cai, K.J. Sullivan, A formal model for automated software modularity and evolvable analysis. *ACM Trans. Softw. Eng. Methodol.* 21(4) (2012) art. no. 21
10. S.K. Chandrasegaran, K. Ramani, R.D. Sriram, I. Horvath, A. Bernard, R.F. Harik, W. Gao, The evolution, challenges, and future of knowledge representation in product design systems. *CAD* 45(2) (2013) 204–228.
11. J.M.P. Cardoso, M. Hubner (eds), *Reconfigurable Computing: From FRGAs to Hardware/Software Codesign*. Springer, 2011.
12. K. Compton, S. Hauck, Reconfigurable Computing: a survey of systems and software. *ACM Computing Surveys* 34(2) (2002) 171–210.
13. R. Conradi, B. Westfechtel, Versions models for software configuration management. *ACM Comput. Surv.* 30(2) (1998) 232–282.
14. B. Corbett, D.W. Rosen, A configuration design based method of platform commonization for product families. *AI EDAM* 18(1) (2004) 21–39.
15. J. Dahmus, J.P. Gonzalez-Zugasti, K.N. Otto, Modular product architecture, *Design Studies* 22(5) (2001) 409–424.
16. X. Du, J. Jiao, M.M. Tseng, Architecture of product family: Fundamentals and methodology. *Concurrent Eng.: Res. and Appl.* 9(4) (2001) 309–325.
17. X. Du, J. Jiao, M.M. Tseng, Product platform modeling and design support: An approach based on graph rewriting systems. *AI EDAM* 16(2) (2002) 103–120.
18. H.A. ElMaraghy (ed), *Changeable and Reconfigurable Manufacturing Systems*. Springer, 2009.
19. S.K. Ethiraj, D. Levinthal, Modularity and innovation in complex systems. *Management Science* 59(2) (2004) 159–173.
20. F.J. Erens, *The synthesis of variety: developing product families*. PhD thesis, Eindhoven Univ. of Technology, 309 p., 1996.

21. R. Fellini, M. Kokkolaras, P. Papalambros, Commonality decisions in product family design. In: T.W. Simpson, J. Siddique, J. Jiao (eds.), *Product Platform and Product Family Design: Methods and Applications*. Springer, New York, 157-185, 2006.
22. S. Ferguson, E. Kasprzak, K. Lewis, Designing a family of reconfigurable vehicles using multilevel multidisciplinary design optimization. *Structural and Multidisciplinary Optimization* 39(2) (2008) 171-186.
23. S.K. Fixson, Modularity and commonality research: past developments and future opportunities. *Concurrent Engineering: Research and Applications* 15(2) (2007) 85-11.
24. C.D. Fletcher, Adaptable design quantification. PhD Dissertation, Dept. of Mechanical and Manufacturing Engineering, Univ. of Calgary, Calgary Canada, 2007.
25. J.D. Frutos, E.R. Santos, D. Borenstein, Decision support system for product configuration in mass customization environments. *Concurrent Engineering: Res. and Appl.* 12(2) (2004) 131-144.
26. K. Fujita, Product variety optimization under modular architecture. *CAD* 34(12) (2002) 953-965.
27. K. Fujita, H. Yoshida, Product variety optimization simultaneously designing module combination and module attributes. *Concurrent Engineering: Research and Applications* 12(2) (2004) 105-118.
28. K. Fujita, H. Amaya, R. Akai, Mathematical model for simultaneously design of module commonalization and supply chain configuration toward global product family. *J. of Intelligent Manufacturing* 24(5) (2013) 991-1004.
29. M.R. Garey, D.S. Johnson, *Computers and Intractability. The Guide to the Theory of NP-Completeness*. W.H. Freeman & Company, San-Francisco, 1979.
30. R. Garud, A. Kumaraswamy, R. Langlois (eds), *Managing in the age of modularity: architecture, networks, and organizations*. Wiley, New York, 2009.
31. Y. Gerchak, M.J. Magazine, A.B. Camble, Component commonality with service level requirements. *Management Science* 34(6) (1988) 753-760.
32. J.K. Gershenson, G.J. Prasad, S. Allamneni, Modular product design: A life-cycle view. *Trans. of the SDPS* 3(4) (1999) 13-26.
33. J.P. Gonzalez-Zugasti, K.N. Otto, J.D. Baker, A method for architecting product platform. *Res. in Eng. Des.* 12(2) (2000) 61-72.
34. J.P. Gonzalez-Zugasti, K.N. Otto, J.D. Baker, Assessing value in platform product family design. *Res. in Eng. Des.* 13(1) (2002) 30-41.
35. P. Gu, M. Hashemian, A.Y.C. Nee, Adaptable design. *Annals of CIRP* 53(2) (2004) 539-557.
36. C.T. Hansen, A. Riitahuhta, Issues on the development and application of computer tools to support product structuring and configuring. *Int. J. of Technology Management* 21(3/4) (2001) 240-256.
37. M. Hashemian, Design for adaptability. PhD Dissertation, Dept. of Mech. Eng., Univ. of Saskatchewan, Saskatoon, Canada, 2005.
38. P.T. Helo, Q.L. Xu, S.J. Kyllonen, R.J. Jiao, Integrated vehicle configuration system - connecting the domains of mass customization. *Computers in Industry* 61(1) (2010) 44-52.
39. C.C. Huang, A. Kusiak, Modularity in design of products and systems. *IEEE Trans. on Syst., Man and Cybern. - Part A* 28(1) (1998) 66-77.
40. J.R. Jiao, T.W. Simpson, Z. Siddique, Product family design and platform-based product development: a state-of-the-art review. *J. of Intelligent Manufacturing* 18(1) (2007) 5-29.
41. A.K. Kamrani, S.M. Salhich, *Product Design for Modularity*. Kluwer, 2000.
42. M.E. Kasarda, J.P. Terpenney, D. Inman, K.R. Precoda, J. Jelesko, A. Sahin, J. Park, Design for adaptability (DFAD) - a new concept for achieving sustainable design. *Robotics Computer-Integrated Manufacturing* 23(6) (2007) 727-734.
43. K. Keutzer, S. Malik, A.R. Newton, J.M. Rabaey, A. Sangiovanni-Vincentelli, System-Level Design: Orthogonalization of Concerns and Platform-Based Design. *IEEE Trans. on Computer-Aided Design of Integrated Circuits and Systems* 19(12) (2000) 1523-1543.
44. D.-J. Kim, B. Kogut, Technological platforms and diversification, *Organ. Sci.* 7(3) (1996) 283-301.
45. Y. Koren, U. Heisel, F. Jovane, T. Moriwaki, G. Pritschow, G. Ulsoy, H. Van Brussel, Reconfigurable manufacturing systems. *Annals of CIRP* 48(2) (1999) 527-540.
46. M.Sh. Levin, *Combinatorial Engineering of Decomposable Systems*. Kluwer, Dordrecht, 1998.
47. M.Sh. Levin, Modular system synthesis: example for composite packaged software. *IEEE Trans. on SMC, Part C* 35(4) (2005) 544-553.



48. M.Sh. Levin, *Composite Systems Decisions*. Springer, London, 2006.
49. M.Sh. Levin, Combinatorial technological systems problems (examples for communication system). In: *Proc. of Int. Conf. on Systems Engineering and Modeling ICSEM-2007*, Israel, pp. 24–32, 2007.
50. M.Sh. Levin, Combinatorial optimization in system configuration design, *Autom. & Remote Control* 70(3) (2009) 519–561.
51. M.Sh. Levin, Towards configuration of applied Web-based information system. Electronic preprint, 13 pp., Aug. 31, 2011. <http://arxiv.org/abs/3108.3865> [cs.SE]
52. M.Sh. Levin, Aggregation of composite solutions: strategies, models, examples. Electronic preprint. 72 pp., Nov. 29, 2011 <http://arxiv.org/abs/1111.6889> [cs.SE]
53. M.Sh. Levin, Morphological methods for design of modular systems (a survey). Electronic preprint, 20 pp., Jan. 9, 2012. <http://arxiv.org/abs/1201.1712> [cs.SE]
54. M.Sh. Levin, Towards electronic shopping of composite product. Electronic Preprint. 10 pp., March 3, 2012. <http://arxiv.org/abs/1203.0648> [cs.SE]
55. M.Sh. Levin, Multiset estimates and combinatorial synthesis. Electronic preprint. 30 pp., May 9, 2012. <http://arxiv.org/abs/1205.2046> [cs.SY]
56. M.Sh. Levin, Combinatorial synthesis of communication protocol ZigBee with interval multiset estimates. In: *Proc. of Int. 4nd It. Conf. on Ultra Modern Telecommunication ICUMT-2012*, St. Petersburg, pp. 29–34, 2012.
57. M.Sh. Levin, Towards design of system hierarchy (research survey). Electronic preprint. 36 pp., Dec. 7, 2012. <http://arxiv.org/abs/1212.1735> [math.OC]
58. M.Sh. Levin, Clique-based fusion of graph streams in multi-function system testing. *Informatica* 23(3) (2012) 391–404
59. M.Sh. Levin, Note on combinatorial engineering frameworks for hierarchical modular systems. Electronic preprint. 11 pp., Mar. 29, 2013. <http://arxiv.org/abs/1304.0030> [math.OC]
60. M.Sh. Levin, Improvement/extension of modular systems as combinatorial reengineering (survey). Electronic preprint, 24 pp., Apr. 17, 2013. <http://arxiv.org/abs/1304.4965> [cs.AI]
61. M.Sh. Levin, Note on evaluation of hierarchical modular systems. Electronic preprint, 15 pp., May 21, 2013. <http://arxiv.org/abs/1305.4917> [cs.AI]
62. M.Sh. Levin, Towards detection of bottlenecks in modular systems. Electronic preprint, 12 pp., June 1, 2013. <http://arxiv.org/abs/1306.0128> [cs.AI]
63. M.Sh. Levin, Towards multistage design of modular systems. Electronic preprint, 13 pp., June 19, 2013. <http://arxiv.org/abs/1306.4635> [cs.AI]
64. M.Sh. Levin, Towards combinatorial evolution of composite systems. *Expert Systems with Applications* 40(4) (2013) 1342–1351
65. M.Sh. Levin, A modular approach to the communication protocol and standard for multimedia information: a review. *J. of Commun. Technol. and Elect.* 58(6) (2013) 594–601.
66. M.Sh. Levin, Modular design and improvement of the management system in the smart home with the use of interval multiset estimates. *J. of Commun. Technol. and Elect.* 58(6) (2013) 584–593.
67. M.Sh. Levin, *Modular system design and evaluation*. Springer, 2015.
68. M.Sh. Levin, M.L. Nisnevich, Combinatorial scheme for management of life cycle: Example for concrete macrotechnology. *J. of Intell. Manuf.* 12(4) (2001) 393–401.
69. M.Sh. Levin, L.V. Sokolova, Hierarchical combinatorial planning of medical treatment. *Computer Methods and Programs in Biomedicine* 73(1) (2004) 3–11
70. M.Sh. Levin, M. Firer, Hierarchical morphological design of immunoassay technology. *Computers in Biology and Medicine* 35(3) (2005) 229–245.
71. M.Sh. Levin, M.A. Danieli, Hierarchical decision making framework for evaluation and improvement of composite systems (example for building). *Informatica* 16(2) (2005) 213–240.
72. M.Sh. Levin, I.A. Khodakovskii, Structural design of the telemetry system. *Autom. and Remote Control* 68(9) (2007) 1654–1661.
73. M.Sh. Levin, O. Kruchkov, O. Hadar, E. Kaminsky, Combinatorial systems evolution: example of standard for multimedia information. *Informatica* 20(4) (2009) 519–538.
74. M.Sh. Levin, A. Andrushevich, R. Kistler, A. Klapproth, Combinatorial evolution of ZigBee protocol. In: *Proc. of IEEE Region 8 Int. Conf. SIBIRCON-2010*, vol. 1, Irkutsk, pp. 314–319, 2010.
75. M.Sh. Levin, A.V. Fimin, Configuration of alarm wireless sensor element. In: *Proc. of 2nd Int. Conf.*

- on *Ultra Modern Telecommunication ICUMT-2010*, Moscow, pp. 924–928, 2010.
76. Y. Li, D. Xue, P. Gu, Design for product adaptability. *Concurrent Engineering: Research and Applications* 16(3) (2008) 221-232.
  77. M.V. Martin, *Design for variety: a methodology for developing product platform architecture*. PhD thesis, Stanford Univ., 172 p., 1999.
  78. M.V. Martin, K. Ishii, Design for variety: developing standardized and modularized product platform architecture. *Res. in Eng. Des.* 13(4) (2002) 213-235.
  79. J. McDermott, R1: a rule-based configurer of computer systems. *Artif. Intell.* 19(2) (1982) 39–88.
  80. P.K. McKeenly, S.D. Sadjadi, E.P. Kasten, B.H.C. Cheng, Composing adaptive software. *IEEE Computer* 37(7) (2004) 56–64.
  81. M.H. Meyer, A.P. Lehnerd, *The Power of Product Platforms: Building Values and Cost Leadership*. Free Press, New York, 1997.
  82. B.G. Mirkin, *Clustering for Data Mining: A Data Recovery Approach*. Chapman & Hall / CRC, 2005.
  83. Z. Navabi, *VHDL: Modular Design and Synthesis of Cores and Systems*. 3 ed., McGraw-Hill, 2007.
  84. G.L. Nemhauser, L.A. Wolsey, *Integer and Combinatorial Optimization*. Wiley, 1999.
  85. C.H. Papadimitriou, K. Steiglitz, *Combinatorial Optimization: Algorithms and Complexity*. Courier Dover Publications, New York, 1998.
  86. B. Prasad, Designing products for variety and how to manage complexity. *J. of Product and Brand Management* 7(3) (1998) 208-222.
  87. F.S. Roberts, *Discrete Mathematical Models with Applications to Social, Biological, and Environmental Problems*. Pearson, 1976.
  88. D. Robertson, K. Ulrich, Planning for product platforms. *Sloan Manag. Review* 39(4) (1998) 19-34.
  89. B. Roy, *Multicriteria Methodology for Decision Aiding*. Kluwer, Dordrecht, 1996.
  90. D. Sabin, R. Weigel, Product configuration frameworks - a survey. *IEEE Intelligent Systems* 13(4) (1998) 42-49.
  91. H.A. Simon, A. Newell, Heuristic problem solving: the next advance in operations research. *Operations Research* 6(1) (1958) 1-10.
  92. T.W. Simpson, J.R.A. Maier, F. Mistree, Product platform design: methods and application. *Res. in Eng. Des.* 13(1) (2001) 2-22.
  93. T.W. Simpson, Z. Siddique, R.J. Jiao (eds) *Product Platform and Product Family Design*. Springer, 2006.
  94. T.W. Simpson, R.J. Jiao, Z. Siddique, K. Holttä-Otto (eds) *Advances in Product Family and Product Platform Design*. Springer, 2014.
  95. T. Soininen, J. Tiihonen, T. Mannisto, R. Sulonen, Towards a general ontology of configuration. *AI EDAM* 12(4) (1998) 295-300.
  96. X. Song, W. Dou, A workflow framework for intelligent service composition. *Future Generation Computer Systems* 27(5) (2011) 627-636.
  97. R. Spicer, Y. Koren, M. Shpitalni, D. Yip-Hoi, Design principles for machining system configurations. *Annals of CIRP* 51(1) (2002) 275-280.
  98. V. Tam, K.T. Ma, Optimizing personal computer configurations with heuristic-based search methods. *Artificial Research Review* 17(2) (2002) 129-140.
  99. X. Tang, C. Jiang, M. Zhou, Automatic Web service composition based on Horn clauses and Petri nets. *Expert Systems with Applications* 38(10) (2011) 13024-13031.
  100. B. Wielinga, G. Schreiber, Configuration-design problem solving. *IEEE Expert: Intelligent Systems and Their Applications* 12(2) (1997) 49–56
  101. D. Xue, G. Hua, V. Mehrad, P. Gu, Optimal adaptable design for creating the changeable product based on changeable requirements considering the whole product life-cycle. *J. of Manufacturing Systems* 31(1) (2012) 59-68.
  102. D. Yang, M. Dong, R. Miao, Development of a product configuration system with ontology-based approach. *CAD* 40(8) (2008) 863-878.
  103. C. Zopounidis, M. Doumpos, Multicriteria classification and sorting methods: A literature review. *Eur. J. of Oper. Res.*, 138(2) (2002) 229-246.